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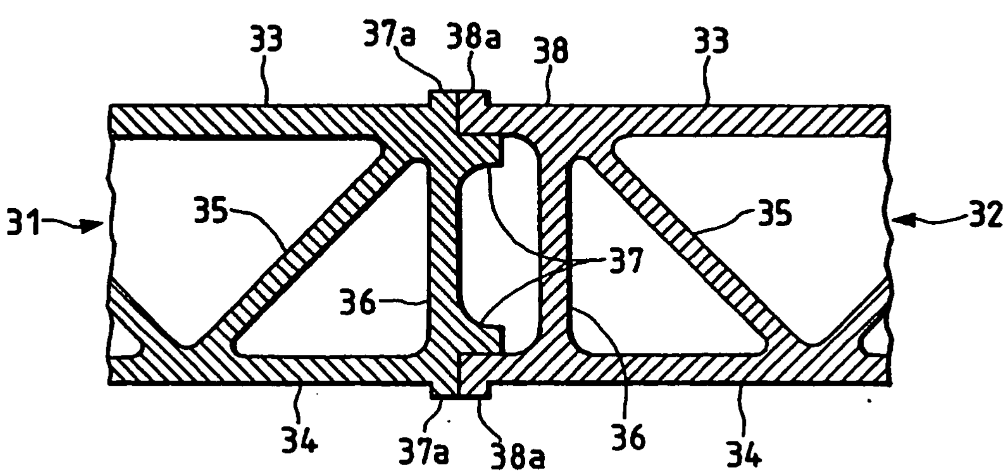
(54) **Friction stir welding method**

(57) This invention provides a configuration of a joint that allows a satisfactory welded joint to be formed with reduced deformation of the join't region when two-face structures (panels) are friction-welded end to end. The panels 31, 32 each have two substantially parallel plates 33, 34 and a third member 35 connecting the two plates 33, 34. The end portions of the plates 33, 34 of one panel 32 are friction-welded to the end portions of the plates 33, 34 of the other panel 32. At least one of the panels has a plate 36 at its end for connecting the plates 33 and 34 and has a rigidity to support a pressing force produced during the friction welding.

FIG. 7



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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a friction welding method that is suitably applied to panel welding used, for example, in aluminum alloys railway cars and buildings.

[0002] A two-face structure (panel) for railway cars using hollow shape members is disclosed in Japanese Patent Laid-Open No. 246863/1990, and another using laminated panels such as honeycomb panels is disclosed in Japanese Patent Laid-Open No. 106661/1994.

[0003] Friction stir welding is performed by rotating a round tool inserted in a joint region to heat and plasticize the joint region thus forming a weld. This welding is applied to a butt joint and a lap joint. This is described in wo 93/10935 (which is the same as wo 0615480B1 and the Published Japanese Translation of PCT Patent Application from another country No. 505090/1995) and the Welding & Metal Fabrication, January 1995, pp. 13-16. Reference should be made to these documents for explanation of friction stir welding, which is employed in the present invention.

[0004] In friction stir welding, the reaction of the plasticized metal being extruded from immediately beneath the rotating tool (round rod) to the surface during the welding results in a downward force acting on the joint region. Thus, when this welding method is applied to a two-face structure (panel), this downward force causes the joint material at the joint region to flow downward, deforming the joint. This makes it impossible to produce a satisfactory weld.

[0005] Two-face structures (panels) include hollow shape members made of extruded aluminum alloy and honeycomb panels. Joining such panels has been accomplished by MIG welding and TIG welding. When the friction welding is applied to such a joint, the joint is bent down or the material in the joint region is forced to flow down by a downward force produced during the friction welding.

[0006] The inventor has found the above phenomena in a variety of experiments.

[0007] Preferably, it is a first object to provide a satisfactory welded joint by minimizing deformation of the joint region when two faces are friction-welded.

[0008] Preferably, it is a second object to provide a satisfactory welded joint when one face is friction-welded.

[0009] It is a third object to enable two faces to be welded together in a short time with little deformation.

[0010] Preferably, it is a third object to enable two faces to be welded together in connecting member that joins two plates forming two faces.

[0011] The second object is realized by providing the members at the joint region with a raised portion that protrudes toward the friction welding tool side.

[0012] The third object is realized by disposing rotary tools for friction welding on both sides of the objects to be welded, placing the rotation center of one of the tools on an extension of the rotation center of the other tool, and performing friction welding simultaneously.

[0013] Figure 1 is a vertical cross section of one embodiment of this invention.

[0014] Figure 2 is a vertical cross section of Figure 1 after friction welding.

[0015] Figure 3 is a vertical cross section of another embodiment of this invention.

[0016] Figure 4 is a vertical cross section of Figure 3 after friction welding.

[0017] Figure 5 is a vertical cross section of another embodiment of this invention.

[0018] Figure 6 is a vertical cross section of Figure 5 after friction welding.

[0019] Figure 7 is a vertical cross section of still another embodiment of this invention.

[0020] Figure 8 is a vertical cross section of Figure 7 after friction welding.

[0021] Figure 9 is a vertical cross section showing the procedure of friction welding of a further embodiment of this invention.

[0022] Figure 10 is a vertical cross section of a further embodiment of this invention.

[0023] Figure 11 is a vertical cross section of a further embodiment of this invention.

[0024] Figure 12 is a vertical cross section of a further embodiment of this invention.

[0025] Figure 13 is a vertical cross section of a further embodiment of this invention.

[0026] Figure 14 is a vertical cross section of a further embodiment of this invention.

[0027] Figure 15 is a perspective view of a structural body of a railway car.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028] The embodiment shown in Figure 1 has a joint configuration of abutting type between hollow shape members 31, 32 as panels. The hollow shape members 31, 32 have vertical plates 36, 36 at their ends in the width direction. Before the welding, the vertical plates 36, 36 are disposed immediately beneath a rotary tool 50. The vertical plates 36, 36 are opposed to each other in contact. If they are spaced apart, the distance is small and approximately 1 mm. On the extension of the interface between the vertical plates 36, 36 lies the center of a projection 52. The vertical plates 36, 36 have a stiffness strong enough to sustain the downward force mentioned earlier. The vertical plates 36 are perpendicular to two plates 33, 34. The hollow shape members 31, 32 are formed by extruding aluminum alloy. The upper and lower faces of the hollow shape member 31 are flush with the corresponding upper and lower faces of the hollow shape member 32. That is, the hollow shape mem-

bers 31, 32 have the same thickness. This is true also of the succeeding embodiments. During the friction welding, the boundary 53 between a large-diameter portion 51 and the projection 52 of a small-diameter portion of the rotary tool 50 is situated above the upper surfaces of the hollow shape members 31, 32. Numeral 35 designates a plurality of members that are arranged in trusses to connect the two plates 36, 36. The hollow shape members 31, 32 each have bilaterally symmetrical end portions. The hollow shape members 31, 32 are mounted on a bed (not shown) and fixed immovably. The bed also lies under the vertical plates 36, 36.

[0029] Friction stir welding is performed by rotating the tool 50, plunging the projection 52 into the joint region of the hollow shape members 31, 32, and moving the projection 52 along the joint region. The rotating center of the projection 52 is between the two vertical plates 36, 36.

[0030] Figure 2 shows the two panels after they are friction-welded. Reference number 45 denotes the shape of a weld bead after welding. On the extension of the border line between the vertical plates 36, 36 is situated the width center of the weld bead 45. The bead 45 lies in an area on the extension of the thickness of the vertical plates 36, 36. The depth of the weld bead 45 is determined by the height of the projection 52 at the lower end of the rotary tool 50 inserted in the joint region.

[0031] With this construction, because the vertical plates 36, 36 perpendicular to the plates 33, 34 sustain the vertical force produced during the friction welding, the joint region does not bend, offering a satisfactory joint as shown in Figure 2. The vertical plate 36 is made vertical to the plates 33, 34 as much as possible.

[0032] The vertical plate 36 may be holed for a lighter weight. This is true also of the succeeding embodiments.

[0033] Welding of the lower side is done by turning the hollow shape members upside down.

[0034] The embodiment of Figure 3 has a vertical plate 36 at the end of one hollow shape member 31 but not at the opposing end of the other hollow shape member 32. Corners in the vertical direction of the vertical plate 36 of the hollow shape member 31 are recessed so as to receive the ends of projecting pieces 38, 38 of the hollow shape member 32. These recessed portions are open in a direction of thickness of the hollow shape member 31 and in a direction perpendicular to the thickness direction (toward the hollow shape member 32 side). When the projecting pieces 38 are placed (superposed) on the recessed portions, there is actually a clearance between them although they are in contact with each other in the figure. There is also a gap between the front ends of these members (i.e., between the projecting pieces 38, 38 and the corners 33a, 34b). The abutting joint portions on the upper face side of the two hollow shape members 31, 32 and the vertical plate 36 are situated directly below the center of the rotary tool 50. The rotating center of the projection 52 of the welding tool 50 is disposed on an extension of the center line of the thickness of the vertical plate 36. That is, the joint region of the plate 33 (34) and plate 33 (34) is situated on the extension of the center line of the thickness of the vertical plate 36. The corners 33b, 34b extending from the plates 33, 34 to the recessed portions lie on an extension of the center line of the thickness of the vertical plate 36. Considering the gap between the corners 33b, 34b and the projecting pieces 38, the corners 33b, 34b are situated slightly to the left of the extension of the center line of the thickness of the vertical plate 36. The vertical plate 36 has a rigidity to support the downward force. The horizontal gap between the front ends of the projecting pieces 38 and the hollow shape member 31 is similar to that shown in Figure 1. The height of the projection 52 of the welding tool 50 is approximately equal to the thickness of the projecting piece 38. The region that is plastic and fluid extends below the projecting piece 38, and comes to have an area larger than the diameter of the projection 52, and the two hollow shape members 31, 32 are friction-welded. It is desirable that the friction weld be so formed as to extend beyond the contact area between the underside of the projecting piece 38 and the vertical plate 36.

[0035] Figure 4 shows the state of the joint after being welded. The weld bead 45 is formed such that the width center of the weld bead 45 is situated on an extension of the thickness center of the vertical plate 36.

[0036] To support the vertical force, it is desirable that the rotating center of the tool 50 be located on the extension of the center line of the thickness of the vertical plate 36. To make the quantity of joint of the left and right hollow shape members 31, 32 equal, it is desirable that the corners 33b, 34b be situated on the extension of the thickness center line of the vertical plate 36. While the projection 52 of the tool 50 should preferably be placed in the range between extension lines of thickness of the vertical plate 36, the thickness of the vertical plate 36 is determined by the vertical force, the position of the projection 52 and the strength of the vertical plate 36. Hence, there may be a case that the thickness of the plate 36 is smaller than the diameter of the projection 52. In view of the possible errors of the position of the rotary tool 50 and those of the corners 33b, 34b, it is desirable that the corners 33b, 34b be positioned in the range between extension lines of thickness of the vertical plate 36, and at least a part of the projection 52 of the tool 50 be situated in the range. This arrangement enables the vertical plate 36 to receive at least a part of the vertical force, substantially preventing the deformation of the joint. As a result, a satisfactory joint can be formed. When the bead 45 is taken as a reference, although the bead 45 is slightly larger than the projection 52, the same as above can be said. This is true also of the other embodiments.

[0037] Compared with the case of Figure 1, this joint configuration can minimize the surface sink of the joint region even when the horizontal gap between the pro-

jecting piece 38 and the hollow shape member 31 is large. As a result, the joint has a good appearance and requires a reduced amount of putty for painting. This is because the gap between the two members is terminated at a depth equal to the thickness of the projecting piece 38. It is also considered that this joint configuration can reduce the weight. Further, because one of the hollow members is fitted into the other, the positioning in the height direction of the two members can be accomplished easily.

[0038] The ends of the hollow shape member 31 are bilaterally symmetrical in shape. The hollow shape member 32 are also bilaterally symmetrical. Alternatively, the hollow shape member 31 has one end shaped as shown in Figure 3 and the other end shaped like the end of the hollow shape member 32 of Figure 3.

[0039] In the embodiment of Figure 5, there is virtually no vertical plate 36 immediately below the corners 33b, 34b of the recessed portion of the hollow shape member 31. The right end of the vertical plate 36 lies on the extension of the corners 33b, 34b. On this extension is the rotating center of the tool 50. The end portion of the hollow shape member 31 is given a rigidity to sustain the vertical force by making the lower projecting piece 37 at the joint thicker and increasing the size of the arcs extending from the front ends of the projecting pieces 37 to the plate 36. The projecting pieces 38 of the other hollow shape member 32 are received in the recessed portions of the projecting pieces 37, as in the preceding embodiment of Figure 3. The second hollow shape member 32 has a vertical plate 36 near the projections 38 for connecting the upper and lower plates 33, 34. This arrangement prevents the joint region from being defective even when there is no vertical plate 36 directly below the corners of the recessed portions. It is noted, however, that below the range of bead 45 there is a vertical plate 36 of the panel 31. Figure 6 shows the state after welding.

[0040] In the embodiment of Figure 5, the plate 36 of the hollow shape member 32 may be removed.

[0041] Figure 7 shows another embodiment, a variation of the preceding embodiment of Figure 5, in which the joint region of the two hollow shape members 31, 32 is provided with raised portions 37a, 38a protruding outside. This makes the joint region thick. The heights of the raised portions 37a, 38a are equal. Other parts are similar to those of Figure 5, except that the vertical plate 36 and the projections 37 are slightly thinner.

[0042] With this configuration, if there is a gap between the raised portions 37a and 38a before welding, the gap is filled with the material of the raised portions 37a, 38a, when welded, improving the appearance and reducing the amount of putty required.

[0043] In conventional welded joints, the weld bead has a sink corresponding to the volume of the lost material 41 that has flowed down by the downward force. In the joint configuration of Figure 7, the rotary tool 50 plasticizes the raised portions 37a, 38a and forces them downward making up for the lost volume of the material 41. Thus, formation of sink can be prevented, providing a satisfactory welded joint. Figure 8 shows the shape of bead 45 after welding. After welding, unnecessary parts, if any, are cut off as shown.

[0044] The raised portions 37a, 38a can also be applied to Figure 1, 3 and 5 and to the subsequent embodiments.

[0045] Figure 9 shows a further embodiment, which allows welding at the upper and lower faces from only one side. The ends of the hollow shape members 31, 32 on the lower side have projecting pieces 34a, 34a protruding flush with the lower plates 34, 34 greatly toward the opposing hollow shape member sides. The front ends of the projecting pieces 34a, 34a are virtually in contact with each other. The front ends of the upper plates 33, 33 are back from the front ends of the lower plates 34a, 34a. The front ends of the upper plates 33, 33 are connected to the lower plates 34, 34 through the vertical plates 36, 36. The vertical plates 36, 36 are connected to intermediate portions of the lower plates 34. The top portions of the vertical plates 36, 36 are provided with recessed portions 39, 39 that receive a joint 60. When mounted on the recessed portions 39, 39, the upper surface of the joint 60 is flush with the upper face of the upper plates 33, 33. The distance between the two vertical plates 36, 36 is long enough for the rotary tool 50 to be inserted and is as short as possible. The relation between the vertical plates 36 and the recessed portions 39 is the same as explained in the embodiments of Figure 5 and Figure 7.

[0046] The welding procedure will be described below. In the state of Figure 9(A), the front ends of the lower plates 34a, 34a are welded by the rotary tool 50. At this time, the hollow shape members 31, 32, including the joint region of the plates 34a, 34a, are mounted on a bed. The upper surface of the bed (that backs the bead) is flat. The height of the projection 52 of the rotary tool 50 is smaller than the thickness of the plates 34a, 34a. This design ensures that the bottom surface after welding is flat. Thus, the bottom side can easily be used as an outer surface of the structure of a railway car or a building (the outer surface being the surface on which no decorative plate is mounted). Generally, the upper face of the friction welded joint tends to be uneven (at a boundary portion 51).

[0047] Next, as shown in Figure 9(B), the joint 60 is mounted between the two hollow shape members 31, 32. The joint 60 is T-shaped in vertical cross section. When both ends of the joint 60 are placed on the recessed portions 39, 39, the lower end of a vertical portion 61 has a clearance between it and the weld bead on the lower plate. The vertical portion 61 may be omitted.

[0048] Next, as shown in Figure 9(C), the joint portion between the joint 60 and the hollow shape member 31 is friction-welded by the rotary tool 50. The rotary tool 50 need not be the same as used in Figure 9(A).

[0049] Then, as shown in Figure 9(D), the joint portion between the joint 60 and the hollow shape member 32 is friction-welded by the rotary tool 50.

[0050] This procedure allows the welding to be performed from one side and eliminates the inversion work. With the inversion work eliminated, there is an advantage that the time required for inversion and positioning and the inversion device are unnecessary, and even the assembly precision is improved.

[0051] Figure 10 shows another embodiment, in which both the upper and lower sides of the hollow shape members 51, 52 are friction-welded at the same time. A rotary tool 50a for the lower side is vertically below the welding tool 50 for the upper side. The projection 52 of the second welding tool 50a faces up. The two welding tools 50, 50a facing each other are moved at the same speed to perform friction welding. Denoted 70, 70 are beds (tables). The rotating centers of the tools 50 and 50a are on the same line, on which is the joint region of the hollow shape members 31, 32.

[0052] Because with this arrangement the rotating center of the second tool 50a is positioned on the extension of the rotating center of the first tool 50, forces balance with each other allowing the joint to be welded in a short time with little deformation. Further, because there is no need to invert the hollow shape members 31, 32, the welding can be performed in a short time with little deformation of the joint.

[0053] This embodiment can be applied other embodiments.

[0054] The preceding embodiments have used hollow shape members as panels to be joined. The following embodiments show the friction welding applied to honeycomb panels. As shown in Figure 11, the honeycomb panels 80a, 80b comprise two surface plates 81, 82, core members 83 having honeycomb-like cells, and edge members 84 arranged along the edges of the surface plates 81, 82, with the core members 83 and the edge members 84 soldered to the surface plates 81, 82 to form integral structures. The surface plates 81, 82, the core members 83 and the edge members 84 are made of aluminum alloy. The edge members 84 are made by extrusion and have a rectangular cross section. All sides of this rectangular cross section is larger in thickness than the surface plates 81, 82. The vertical sides of the mutually contacting edge members 84, 84 have the same thickness as shown in Figure 1. The two honeycomb panels 80a, 80b have the same thickness.

[0055] The embodiment of Figure 11 corresponds to the one shown in Figure 1. The height of the projection 52 of the rotary tool 50 is larger than the thickness of the face plates 81, 82. This allows the face plates 81, 82 and the edge members 84, 84 to be welded. The load acting on the panels 80a, 80b is transmitted mainly by the edge members 84. After being fabricated, the panels 80a, 80b are assembled and friction-welded.

[0056] The embodiment of Figure 12 corresponds to the one shown in Figure 3. The edge member 84 of the honeycomb panel 80a has a generally rectangular cross section and has recesses at the corners. The edge member 84 of the honeycomb panel 80b is like a channel, with its opening facing the honeycomb panel 80a. The open ends of the edge member 84 are put on the recessed portions of the edge member 84 of the honeycomb panel 80a.

[0057] The honeycomb panel corresponding to Figure 5 can be fabricated in a similar manner.

[0058] Figure 13 shows still another embodiment that corresponds to Figure 7. After two honeycomb panels 80a, 80b are assembled, a plate 86 is placed on the face plates 81, 81 and temporarily welded to them. The plate 86 makes up for the material that is plasticized and flows out. In Figure 12, one vertical piece of the edge member of the honeycomb panel 80a is removed. The vertical force is supported by the thickness of the horizontal piece of the edge member 84 and the surrounding parts.

[0059] Figure 14 shows a further embodiment of this invention. The preceding embodiments up to Figure 13 includes panels having two faces (face plates), whereas the embodiment of Figure 14 includes panels 91, 92 having virtually a single face (face plates 94, 94). Friction welding is performed at two locations, at the abutting ends of the panels 91, 92, the outside with face plates 94 and the inner side with no face plates. Therefore, the joint regions on the inner side are provided with narrow face plates (face plates 93, 93). The narrow face plates 93, 93 are supported by vertical plates 96, 96. In this example, too, the vertical plates 96 are virtually perpendicular to the face plates 93, 94. The face plates 93, 94 are provided with raised portions 37a, 38a similar to the ones shown in Figure 7. The face plates 94, 94 have a plurality of reinforcing ribs (plates) 95, 95 at specified intervals. The ribs 95 are T-shaped in cross section. The top surfaces of the ribs 95 are flush with those of the face plates 93 of the joint region. To the top surfaces reinforcing members (such as pillars) may be welded, or the top surfaces serve as mounting seats for articles. Further, the face plates also 93, 93 serve as a seat for controlling the height of the tool 50. A movable body carrying the tool 50 travels along the face plates 93, 93. Because of the provision of the face plates 93, 94, the panels 91, 92 can also be said to form a two-face structure. The panels 91, 92 are extruded shape members.

[0060] While Figure 14 shows the vertical plates 96, 96 of the panels 91 and 92 opposing each other at the joint region, as in the configuration of Figure 1, it is possible to place one of the vertical plates over the other, as shown in Figure 3, 5 and 7.

[0061] Figure 15 shows an example of application of this embodiment to the structural body of a railway car. The structural body has side bodies 101, a roof body 102, a floor body 103, and gable bodies 104 at the ends in the longitudinal direction. The side bodies 101 and the roof body 102 have panels 31, 32, 80a, 80b, 91, 92 whose long sides are oriented in the longitudinal direction of the car. The joining between the side bodies 101

and the roof body 102 and between the side bodies 101 and the floor body 103 is accomplished by MIG welding. The roof body 102 and the side bodies 101 are often shaped into arcs in cross section. When the panels 91, 92 are used for the side bodies 101, the side having the vertical plates 96 and ribs 96 is made to face to the interior of the car and the reinforcing members constitute pillars.

[0062] The panels 31, 32 of Figure 9 may be combined in a mirror-image arrangement. The end of the projecting plate 34a of each panel is placed on the recessed portion 39 of the plate 33 of the other panel. This obviates the use of the joint 60 and allows the simultaneous friction welding of the joint region both from above and below. The plates 33, 34a can be provided with raised portions, as shown in Figure 7.

Claims

1. A method of joining two members (31, 32; 80a, 80b; 91, 92) by friction stir welding, comprising the steps of

   arranging said members so that respective joint faces thereof are closely opposed, and
   inserting, at one side of said members, a friction stir welding probe (50) of material harder than that of said members into both said members at the location of said closely opposed joint faces thereof, and rotating said probe so as to effect friction stir welding to join said members,
   wherein at least one of said members has, at said one side thereof, a raised portion (37a, 38a; 86) which is adjacent said joint face thereof and protrudes towards the probe so as to make the joint region thick, said raised portion being contacted by said probe during the friction stir welding and at least partially removed by the probe, and the method includes cutting off the part of said raised portion (37a, 38a; 86) or portions remaining after the friction stir welding by said probe.

2. A method according to claim 1, wherein a gap between said joint faces of the members before welding is filled with the material of the raised portion (37a, 38c) during the welding.

3. A method according to claim 2 wherein, following the friction stir welding and the cutting off of said remaining part of said raised portion or portions, said members, as seen in cross-section across the joining region, have substantially flat and mutually flush joined surfaces at said one side thereof.

4. A method according to claim 1 or 2, wherein the method comprises substantially wholly removing said raised portion (37a, 38a; 86) so that said members, as seen in cross-section across the joining region, have substantially flat and mutually flush joined surfaces at said one side thereof.

5. A method according to claim 4 wherein both of said members are provided respectively with said raised portions, and the method comprises substantially wholly removing both the raised portions so that said members, as seen in cross-section across the joining region, have substantially flat and mutually flush surfaces at said one side thereof.

6. A method according to any one of claims 1 to 5, wherein said raised portion (37a, 38a; 86), prior to the friction stir welding, stands up higher than any other part of the respective member at said one side of the members.

7. A method according to any one of claims 1 to 5, wherein said raised portion (37a, 38a; 86) is constituted by a local thickening of the respective member at said joint face thereof.

8. A method according to any one of claims 1 to 7, wherein each of said members is provided with a said raised portion (37a, 38a; 86), the respective raised portions substantially abutting each other when said joint faces are closely opposed, and said probe (52) contacts and at least partially removes both said raised portions.

9. A method according to any one of claims 1 to 8, wherein the or each said raised portion (37a, 38a) is in one-piece with the member on which it is provided.

10. A method according to any one of claims 1 to 8, wherein said raised portion is a separate piece (86) connected to said member on which it is provided prior to the welding.

11. A method according to any one of claims 1 to 8, wherein said raised portion (86) on one said member extends over said outer face of the other said member when said members are arranged for welding, and said probe (52) penetrates through said raised portion when inserted into the members.

12. A method according to any one of claims 1 to 11, wherein by the friction stir welding, a welding bead (45) is formed at a region of said two members beneath the location of said raised portion or portions (37a, 38a).

13. A method according to any one of claims 1 to 12, wherein said two members are first and second metal panels (31, 32, 80a, 80b; 91, 92) which are

joined together edge-to-edge to form a panel structure by the friction stir welding,

each said panel having at said one side a first face sheet (33, 81; 94) and at its opposite side a web (34; 82; 93) parallel to and spaced from said first face sheet, and having at least one cross-member (36; 94) connecting said face sheet and said web,

said first face sheets (38; 81; 94) of respectively said first and second panels being joined directly by the weld joint, at which a weld bead (45) is formed by the friction stir welding,

said cross-member (36; 94) of at least one of said panels constituting a weld-support cross-member which has one end located at the edge of the panel at which said weld joint is provided, extends across the panel in a transverse direction which is at an angle to said first face sheet of the panel, and has a thickness and location such that said welding bead (45) lies at least partly in the projection area of said cross-member in said transverse direction.

14. A method according to claim 13, wherein said first and second panels (38; 81; 94) both have a said weld-support cross-member (36; 94) at their respective edges at which said weld joint is provided, the respective weld-support cross-members lying alongside each other.

15. A method according to claim 14, including forming two said weld joints at opposite sides of the panel structure by twice performing the friction stir welding, said two weld joints lying respectively at opposite ends of said weld-support cross-members (36; 94).

16. A method according to claim 15, wherein said web of each of said first and second panels is a second face sheet (34; 82).

17. A method according to claim 16, wherein, at said edges of said first and second panel at which said at least one weld joint is formed, said first and second face sheets thereof are comprised of a sheet member (81, 82) and a portion of a reinforcing edge body (84) which is connected by brazing to said sheet member, said welding bead is formed in both said sheet member and said reinforcing edge body, and said reinforcing edge body (84) provides said weld-support cross-member.

18. A method according to claim 13, wherein said first face sheet of one of said panels has a projecting edge portion (38) and the other of said panels has a rebate (33b, 34b) receiving said projecting edge portion.

19. A method according to claim 18, wherein said web of one of said panels also has a projecting edge portion (38) and the other of said panels has a rebate (34b) receiving said projecting edge portion of said web.

FIG. 1

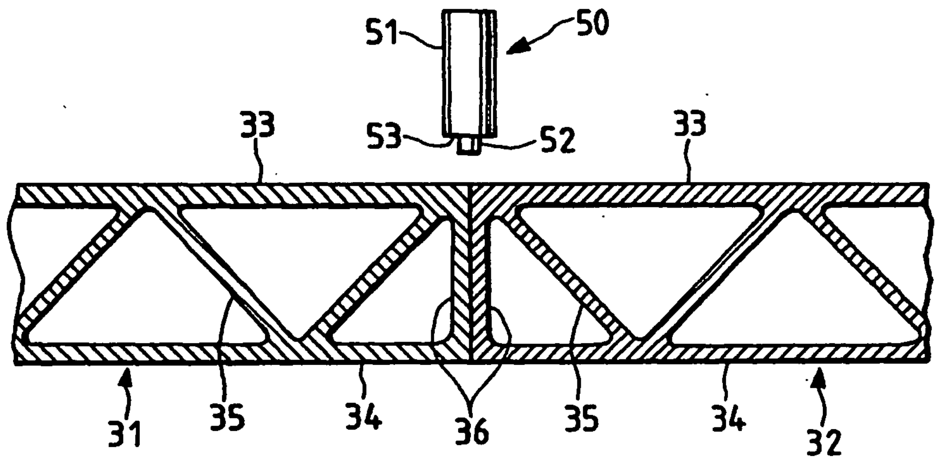


FIG. 2

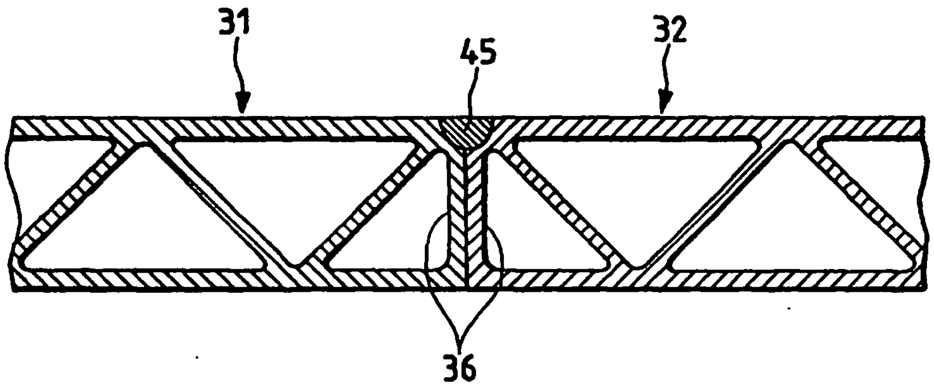


FIG. 3

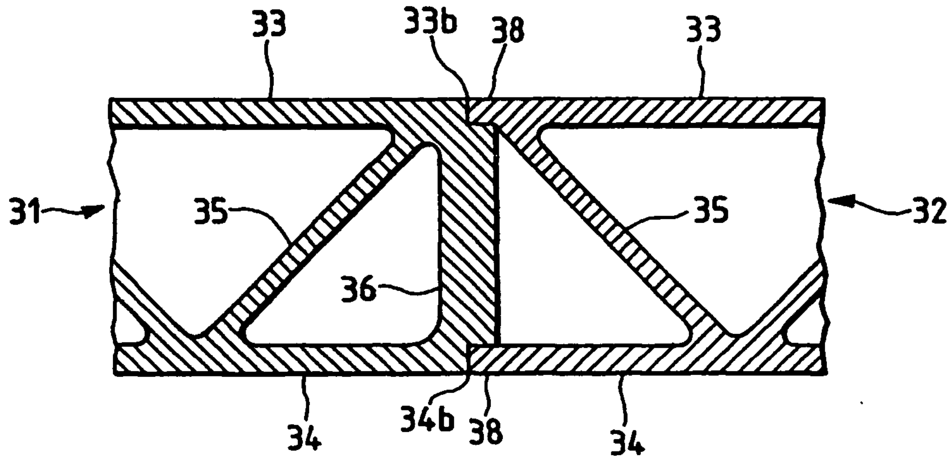


FIG. 4

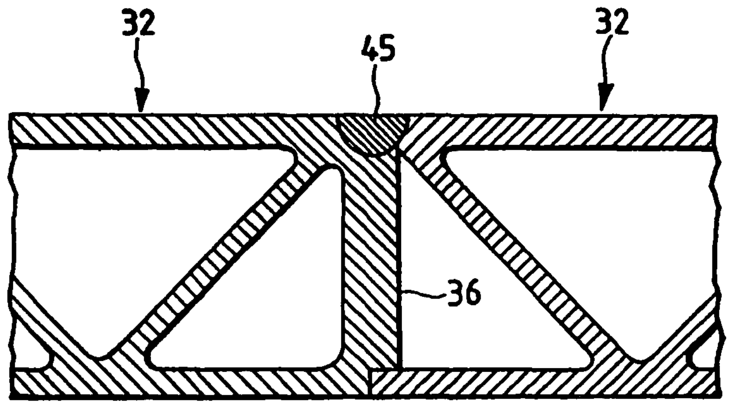


FIG. 5

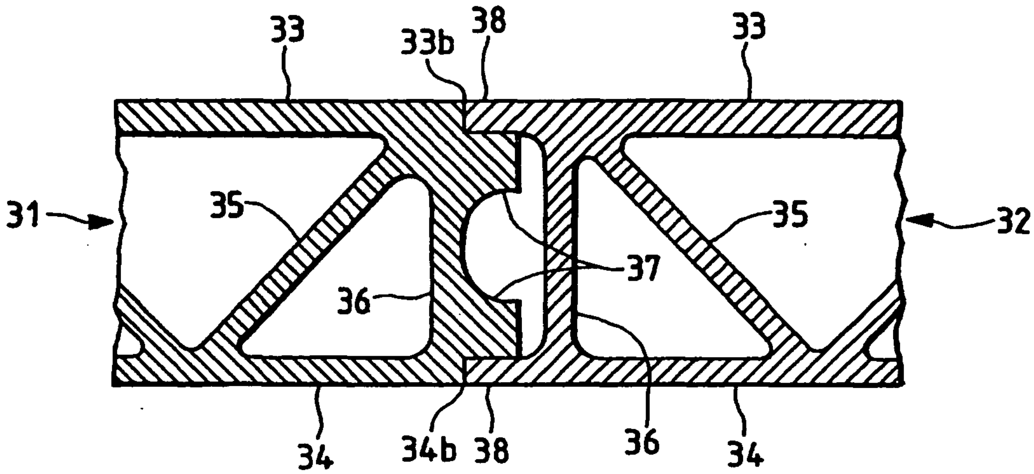


FIG. 6

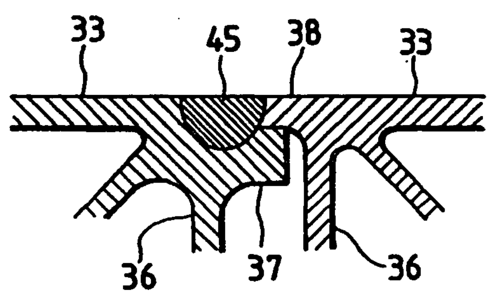
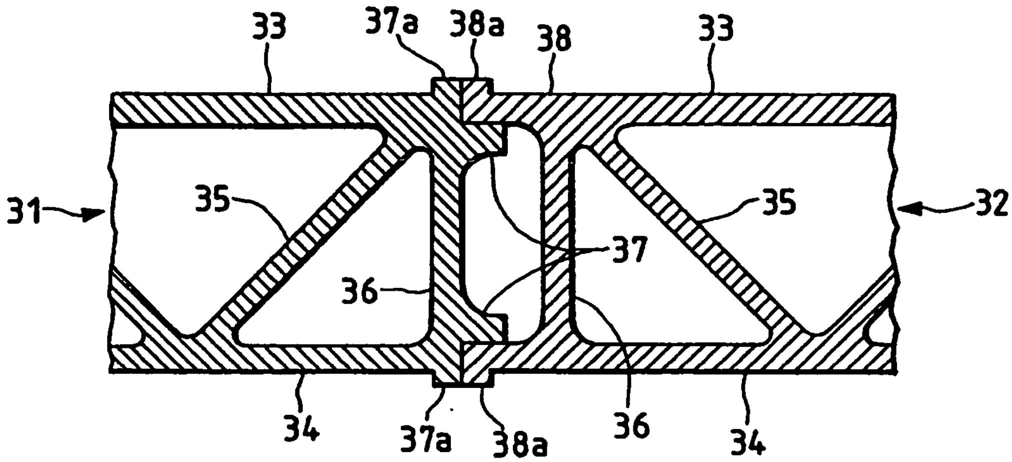


FIG. 7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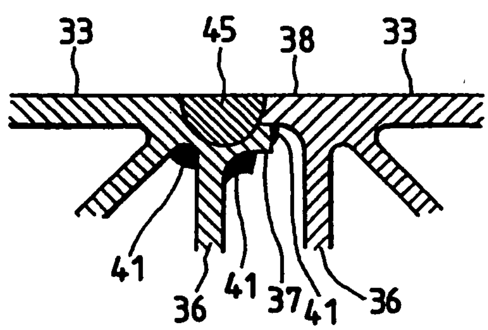
38a
38
33
31
35
35
32
37
36
34
37a
38a
36
34

FIG. 8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36

FIG. 9(A)

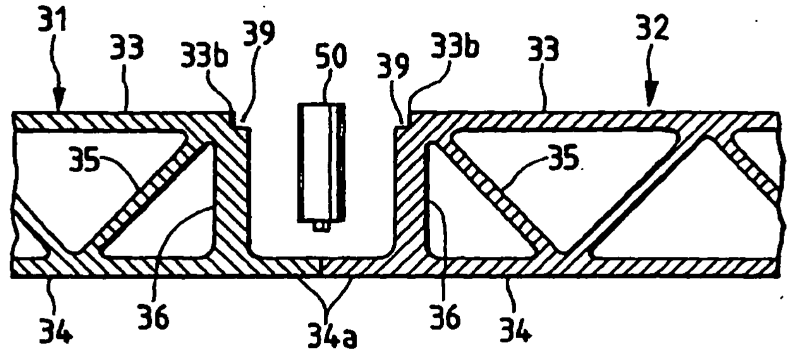

FIG. 9(B)

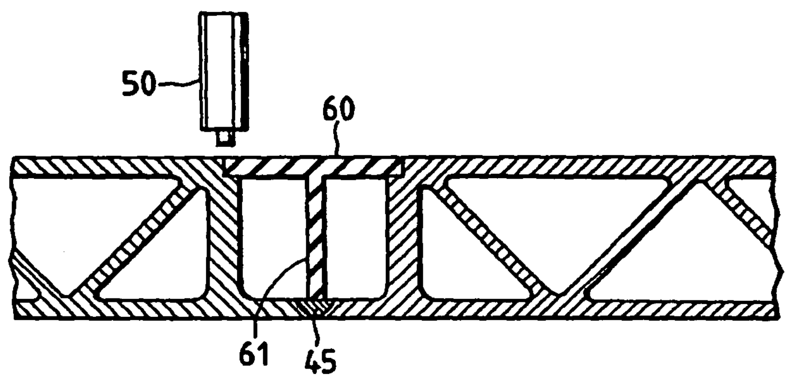

FIG. 9(C)

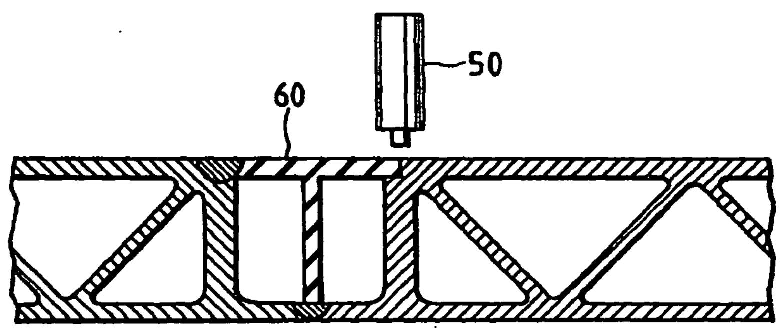

FIG. 9(D)

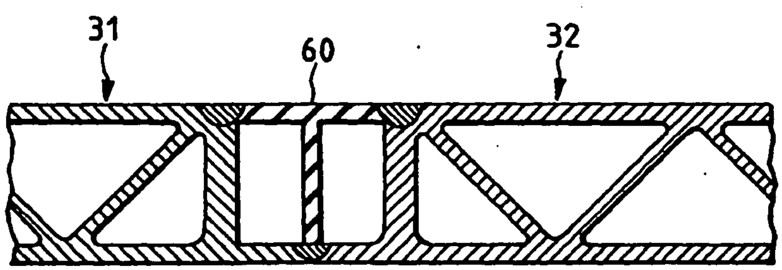

FIG. 10

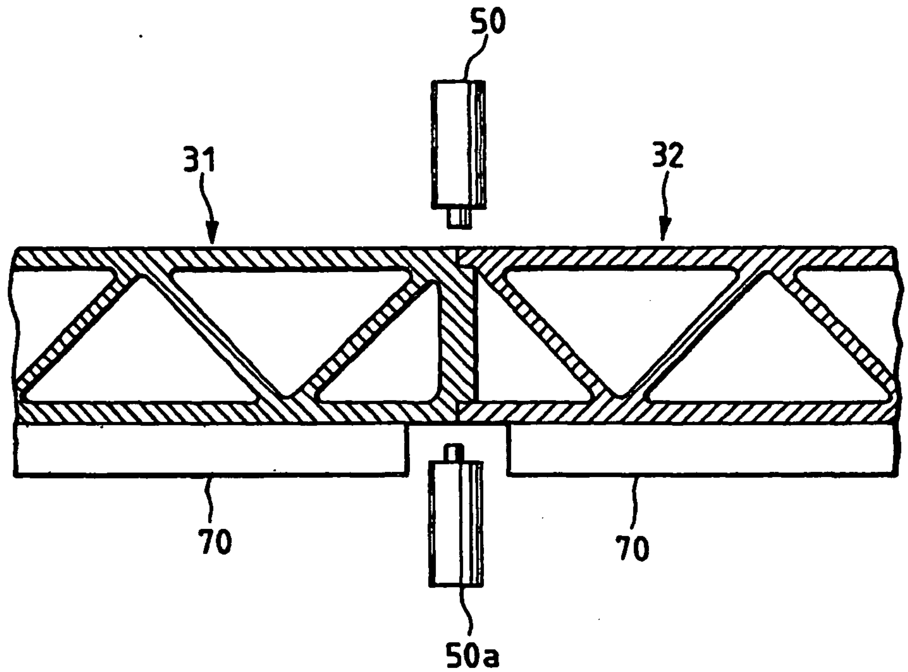

FIG. 11

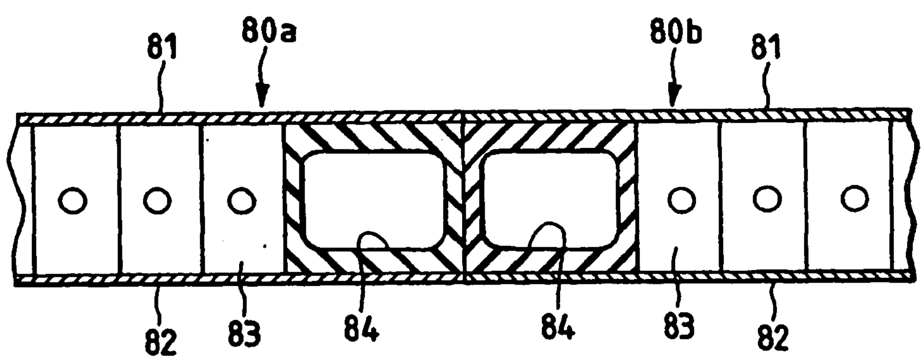

FIG. 12

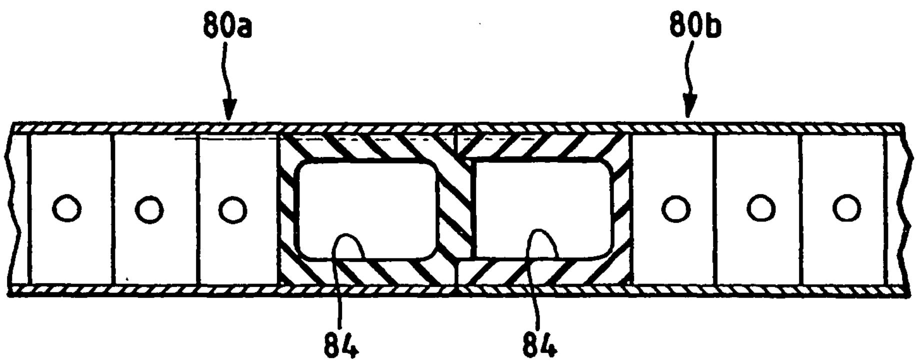

FIG. 13

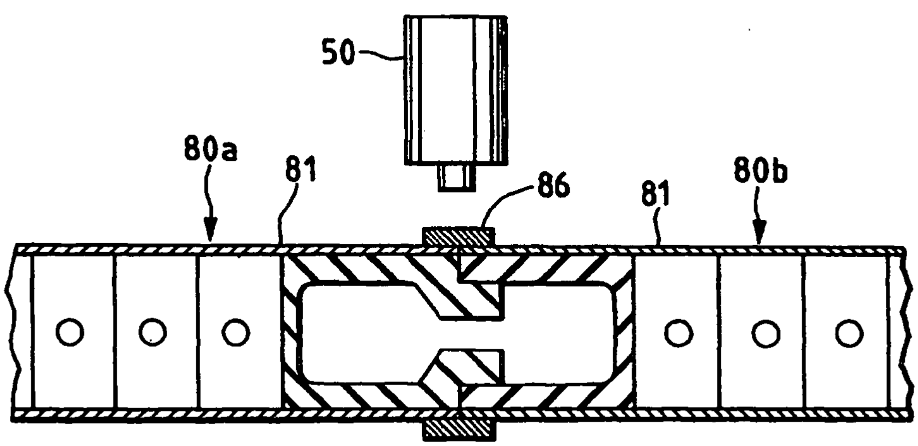

FIG. 14

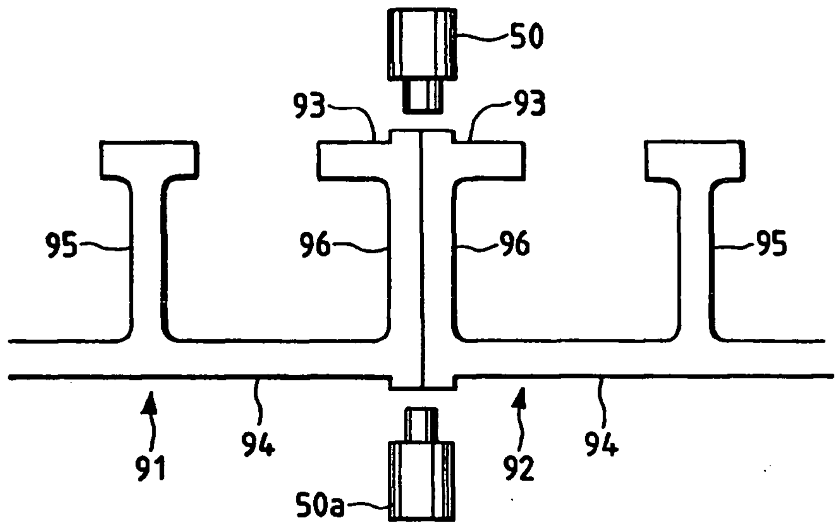

FIG. 15